



**UNIVERSITI PUTRA MALAYSIA**

**USE OF MULTIPLE REGRESSION MODEL TO RELATE WASTE  
COMPOSITION WITH ENERGY CONTENT OF REFUSE-DERIVED  
FUEL**

**CHEE THIAM MING.**

**FPAS 2006 2**

**This thesis is dedicated to my beloved parents for their endless support**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in  
fulfilment of the requirement for the degree of Master Science

**USE OF MULTIPLE REGRESSION MODEL TO RELATE  
WASTE COMPOSITION WITH ENERGY CONTENT  
OF REFUSE-DERIVED FUEL**

By

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**May 2006**

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**Faculty: Environmental Studies**

The amount of wastes in Malaysia has increased tremendously as a result of rapid economic growth. Currently, landfill is the only method for the disposal of solid wastes in the country. It was estimated that about 16,000 tons of municipal solid wastes ended up in landfill everyday. This scenario has worsen when existing landfills are fast filling up and the possibility of getting a new landfill is becoming more difficult because of land scarcity and increase of land prices especially in the urban areas. Further, as the environmental impact of existing landfills has started to become more apparent, the government is under pressure to find a better solution to dispose the wastes without having to incur excessive costs. This study was thus initiated as part of the effort to examine the feasibility of converting solid wastes into refuse-derived-fuel (RDF). The objectives of this study were to determine the relationship between the different waste composition and the calorific value of Refuse Derived Fuel in order to develop models to estimate the calorific value (energy output) of Refuse Derived Fuel based on the specific waste

composition. The results from this study revealed that food waste was the biggest portion in Kajang (44%) followed by plastic (13.2%), paper (10.5%) and yard waste (9.3%). The correlation indicated that food wastes, yard wastes and paper wastes were correlated negatively with the calorific value while plastic is the only waste component having positive correlations with RDF calorific value. Three non-linear regression models were developed from the experimental results. The first model is found to be  $LCV_{wet} (kcal/kg) = 10^{(3.4643 + 0.001736 Fd + 0.005781 Pls - 0.007268 M)}$ , where Fd is food waste, Pls is plastics, and M is moisture. The adjusted  $R^2$  for this model was 0.8706. The second model is found as  $LCV_{wet} (kcal/kg) = 10^{(0.57013 + 0.02618 M + 0.03375 VM)}$  where M is moisture, and VM is volatile matter. The adjusted  $R^2$  for this model was 0.6163. The final model developed from this study is  $LCV_{dry} (kcal/kg) = (0.044549 - 0.000283 C + 0.000168 Oxy)^{-5/2}$  and the independent variable was carbon (C) and oxygen (O) content. The adjusted  $R^2$  was 0.8227. From this study, it can be concluded that calorific value can be estimated through regression model based on physical composition, ultimate and proximate analysis, and the models were also more accurate than models developed by other researchers for solid waste.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk ijazah Master Sains

**PENGUNAAN MULTIPLE REGRESSION MODEL UNTUK  
MEMPERKAITKAN KOMPOSISI SISA PEPEJAL DENGAN  
KANDUNGAN TENAGA REFUSE DERIVED FUEL**

Oleh

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Penghasilan sisa di Malaysia telah bertambah dengan mendadak disebabkan oleh pembangunan ekonomi yang pesat. Pada masa kini, hanya tapak pelupusan sisa yang digunakan sebagai cara pelupusan sisa pepejal di negara ini. Sebanyak 16,000 ton sisa pepejal dianggarkan dilupuskan di tapak pelupusan sisa setiap hari. Senario ini menjadi semakin teruk apabila tapak pelupusan sedia ada semakin penuh dan kemungkinan untuk mendapatkan tapak pelupusan baru adalah rendah disebabkan oleh kekurangan tanah lapang dan peningkatan harga tanah terutamanya di kawasan bandar. Di samping itu, impak tapak pelupusan ke atas alam sekitar menjadi semakin ketara menyebabkan pihak kerajaan menghadapi tekanan untuk mendapatkan cara yang lebih baik bagi melupuskan sisa tanpa mengenakan kos yang tinggi. Kajian ini telah dimulakan sebagai satu usaha untuk mengkaji kemungkinan penukaran sisa-kepada-tenaga (Refuse Derived Fuel). Objektif kajian ini adalah untuk menentukan hubungan di antara komposisi sisa yang berlainan terhadap nilai kalori *Refuse Derived Fuel* supaya model untuk menganggarkan

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nilai kalori (keluaran tenaga) Refuse Derived Fuel boleh dilakukan berdasarkan komposisi sisa tertentu. Kajian ini menunjukkan bahawa komposisi sisa makanan adalah tertinggi di Kajang (44 peratus), diikuti dengan plastik (13.2 peratus), kertas (10.5 peratus) dan sisa halaman (9.3 peratus). Pertalian diantara komposisi sisa dan nilai kalori RDF menunjukkan sisa makanan, sisa halaman dan sisa kertas berkadar negatif dengan nilai kalori dan hanya sisa plastik yang berkadar positif dengan nilai kalori RDF. Tiga model regresi tak linear telah dihasilkan dari keputusan eksperimen. Model pertama didapati sebagai  $LCV_{wet} (kcal/kg) = 10^{(3.4643 + 0.001736 Fd + 0.005781 Pls - 0.007268 M)}$ , di mana Fd ialah sisa makanan, Pls ialah plastik, dan M ialah kelembapan.  $R^2$  yang telah diubahsuai untuk model ini ialah 0.8706. Model kedua didapati sebagai  $LCV_{wet} (kcal/kg) = 10^{(0.57013 + 0.02618 M + 0.03375 VM)}$  di mana M ialah kelembapan dan VM ialah bahan meruap.  $R^2$  yang telah diubahsuai untuk model ini ialah 0.6163. Model terakhir yang dihasilkan daripada kajian ini ialah  $LCV_{dry} (kcal/kg) = (0.044549 - 0.000283 C + 0.000168 Oxy)^{-5/2}$  dan nilai tidak bergantung ialah kandungan karbon dan hidrogen.  $R^2$  yang telah diubahsuai untuk model juga adalah 0.8227. Daripada kajian ini, kesimpulannya ialah nilai kalori boleh dianggarkan melalui model regresi berdasarkan komposisi fizikal, analisis ultimate dan proximate serta model ini adalah lebih tepat berbanding dengan model yang dibuat oleh pengkaji lain untuk sisa pepejal.

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I certify that an Examination Committee has met on 29<sup>th</sup> May 2006 to conduct the final examination of Chee Thiam Ming on her Master of Science thesis entitled "Use of Multiple Regression Model to Relate Waste Composition with Energy Content of Refuse-Derived Fuel" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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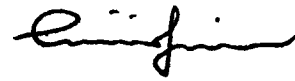
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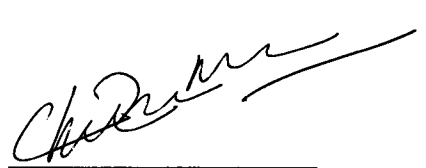


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## DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



**CHEE THIAM MING**

Date : 10 July 2006 .

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Introduction**

Solid wastes are materials or mixture of materials that are discarded by consumers as useless or unwanted (Manser and Keeling, 1996; Tchobanoglous et al., 1993). Manser and Keeling (1996) however argued that solid wastes as a potential energy resource, rated at about 20 on an ideal fuel scale of 110, and having a potential ash content of up to 40% by weight. According to a report by the Ministry of Housing and Local Government Malaysia (2002), the total amount of solid waste generated in Malaysia was about 16,000 tons per day with the average per capita generation rate of about 0.88 kg/day. The amount generated is expected to increase due to the rapid economic and population growth in the country. At present, landfilling is the only method for the disposal of municipal solid wastes in Malaysia and most of these landfill sites are open dumps and posing serious environmental and social threats (Yunus and Kadir, 2003). Disposal of wastes through landfilling is becoming more difficult because existing landfill site are filling up at a very fast rate. At the same time getting new landfill sites is becoming more difficult because of land scarcity and increases of land prices especially in urban areas. Under the Integrated Solid Waste Management Program, the government of Malaysia is searching alternative solutions for the disposal of solid wastes instead of purely landfilling i.e. systems that are technically appropriate without having

to incur excessive costs. One of the alternative technologies is processing raw municipal solid wastes into solid fuels which is called Refuse Derived Fuel (RDF). According to Manser and Keeling (1996), RDF is a fuel manufactured from the combustible fraction of municipal wastes by advanced mechanical processes involving the application of heat and is designed to maximize the recycling potential of the wastes. RDF products should contain less than 15% ash before being used. This waste-to-energy technology has great potential not only it reduces the amounts of wastes to landfill sites but more importantly an attractive way to recycle wastes into heat and power and thus partly substitute the dwindling demands of increasingly more expensive fossil fuels (Schwarz and Brunner, 1983).

This study was carried out to evaluate the physical and chemical characteristics and energy contents of different mixtures of RDF composition from municipal solid wastes in Kajang. The main focus of this study was the application of multiple regression analysis to establish models that can relate the physical composition of solid wastes and energy contents of the RDF products.

In this study, wastes from different areas of Kajang municipality were collected and sorted according to individual waste components. Food wastes, mix plastics, paper and yard waste that were sorted were mixed and a matrix of waste mixture (and in this study is called RDF Mixtures) were prepared and analysed. The “RDF mixtures” were analysed for proximate and ultimate

analysis. The energy contents of the RDF Mixtures were obtained using Bomb Calorimeter.

## **1.2 Statement of Problems**

Compared to landfill and composting, RDF is a new technology for the treatment of solid wastes in Malaysia. Although the technology has proven to be relatively efficient in generating electricity with lower environmental impacts in Europe, the technology may not be directly applicable to Malaysia because of different wastes characteristics and climatic conditions between Malaysia and Europe. In addition, the consistency of getting stable and reliable fuel quality from wastes in Malaysia may have to be investigated thoroughly to reflect the heterogeneous nature of Malaysian wastes and its climatic conditions. At the moment, these “indigenous” information is not available in Malaysia. In the absence of reliable local data, RDF and other waste-to-energy technologies may have to rely on experiences and data generated from other countries. Usage of “foreign” data may be misleading because the actual conditions are different and this result in over or underestimations of data. Production of RDF uses municipal solid wastes as raw materials. Hence it is essential to evaluate the characteristics of local wastes and thus, an assessment of the energy content of RDF with specific waste composition is critical for the effective design and operation of the plant especially when RDF is used before incineration. In other words, detailed characterization of the MSW will allow identification of materials that would contribute to the increase or decrease of the calorific value of RDF. In this

study, a complete and comprehensive study on waste characteristics was carried out in order to develop models for predicting the energy content of RDF.

### **1.3 Objectives of the Study**

This study was carried out to get a comprehensive understanding of the waste composition generated in Kajang municipality. The information was used to establish relationship models between waste composition and the calorific value of RDF products. This will optimize the quality of RDF. The results from this locally generated data can be used to produce representative and reliable information on wastes, that could assist decision makers in the formulation and execution of efficient and cost-effective strategies to deal with Refuse Derived Fuel technologies. The outputs of this study are models that are able to predict the calorific value of RDF from waste compositions.

The specific objectives of the study are as follows:

- a) To identify the physical waste composition of municipal solid waste generated in Kajang municipality;
- b) To determine the relationship between the different waste composition and the calorific value of Refuse Derived Fuel;
- c) To develop models to estimate the calorific value (energy output) of Refuse Derived Fuel based on specific waste composition.

#### 1.4 Significance of the Study

The development of regression models to correlate the energy content of RDF with the physical waste composition provides representative and reliable estimation of the fuel quality in RDF. The significance of this study are as follows:

- This study provides important data and reference for the development of Malaysian standards on RDF quality without having to follow models or standards from other countries that are different in many aspects i.e. waste composition, lifestyle, geographical conditions, demographic, and legal aspects.
- This study has produced methods and formula to produce a better quality RDF with higher calorific value by introducing the appropriate waste components and eliminating less calorific-value materials in RDF.
- This study provides necessary information for the design and operation of RDF processing facilities and the likely characteristics or quality of the recovered products (Luis et. al., 1993). Results from this would avoid unnecessary costs of non-optimal RDF characteristics.



## **1.5 Outline of Thesis**

This report is organized into 5 chapters. Chapter 1 is the general discussion of the study aimed to provide an overview of the concept and the implication of the study. Objective, statement of problems and the significance of the study were also included in this chapter. In Chapter 2, it reviewed and discussed about the current situation on waste management in Malaysia which includes solid wastes generation, composition and characteristic of waste. Waste composition from Asian and some European countries are also provided for comparison. Standard classifications of refuse derived fuel were shown in Table form and the process flow of RDF was illustrated in diagram. The data obtained from the pilot plant in Malaysia are also summarised in this chapter. Prediction models used to estimate the calorific value of solid waste which have been developed in other countries are also referred and presented. Methodology for the study is discussed in detailed in Chapter 3. The approach involved were waste composition study using conning and quarterly method, sorting of waste according to individual waste component, proximate and ultimate analysis, calorific value study of refuse derived fuel using bomb calorimeter, statistical analysis and model-developing. Detailed discussions on the results and findings of the study are presented in Chapter 4, while the conclusions and recommendations for the study are summarised in Chapter 5.